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BLADED DISK VIBRATION

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FINAL REPORT

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1. INTRODUCTION

This report discusses the work accomplished during the NASA grants NAG-231 and NAG-367. Originally, this research program started as NAG-231 and was entitled "The Simulation of Aerodynamic Damping/Mistuning/Friction Interaction in Bladed Disk Vibration". In the second year of NAG-231, a second grant was initiated, NAG-367, entitled "Internship for Graduate Education in Vibration". The activities conducted under these grants were consolidated in the following year and continued as NAG-367, "Bladed Disk Vibration and a Graduate Internship in Vibration." The work reported in this document summarizes the accomplishments of the research conducted under these grants.

The objective of the work was to better understand the vibratory response of bladed disk assemblies that occur in jet engines or turbo-pumps. Two basis problems were investigated:

- (1). How friction damping affects flutter.
- (2). How friction, mistuning, and stage aerodynamics affect resonance.

Understanding these phenomenon allows a better understanding of why some stages have high vibratory stresses, how best to measure those stresses, and what to do about reducing them if they are too large.

2. RESULTS

The results of the research on flutter-friction interaction have been reported in the following papers that constitute section 3 of this report:

1. A. Sinha and Griffin, J.H., "Friction Damping of Flutter in Gas Turbine Engine Airfoils", *AIAA Journal of Aircraft*, Vol. 20, April 1983, pp. 372-376.
2. A. Sinha and Griffin, J.H., "Effects of Friction Dampers on Aerodynamically Unstable Rotor Stages", *AIAA Journal*, Vol. 23, No. 2, February 1985, pp. 262-270.
3. A. Sinha and Griffin, J.H., "Stability of Limit Cycles in a Multi-Degree-of-Freedom Model of an Aerodynamically Unstable Rotor Stage with Friction Dampers", *Journal of Sound and Vibration*, Vol. 103, December 1985, pp. 341-356.

4. A. Sinha, Griffin, J.H., and Kielb, R.E., "The Influence of Friction Dampers on Torsional Blade Flutter," *ASME Journal of Engineering for Gas Turbines and Power*, Vol. 108, April 1986, pp. 313-318.

In these papers we investigated how friction damping affects flutter in aerodynamically unstable stages. Since friction is nearly always present, this work is important in that it provides a basis for understanding why some stages do not flutter when aerodynamic calculations indicate that they should. These results are also important in understanding how to use friction damping devices more effectively as a backup safety feature to prevent flutter under certain severe usage conditions. (Dampers are currently used in turbines to control resonance, the technology developed in this program will allow them to be also used to control flutter).

Briefly, in paper [1] a model of a frictionally damped, aerodynamically unstable airfoil was considered. Mathematical techniques were developed for analyzing its nonlinear response and the resulting solutions were examined to establish the basic physical nature of friction-flutter interaction in the simple context of single blade dynamics. Next, in papers [2] and [3] an approach was established for analyzing stage vibration, first for tuned and then for untuned bladed disk assemblies. Lastly, in [4] supersonic aerodynamics were incorporated into the mathematical model and an actual NASA fan stage was analyzed in order to establish to what extent the performance of a representative stage could be increased by using friction dampers. It was shown that the use of dampers would allow the stage to operate at Mach numbers up to 1.6 whereas without dampers the rotor would flutter at 1.2.

The results of the research on resonant response have been reported in the following papers that constitute section 4 of this report:

5. J.H. Griffin and Hoosac, T.M., "Model Development and Statistical Investigation of Turbine Blade Mistuning", *ASME Journal of Vibration, Stress, and Reliability in Design*, Vol. 106, April 1984, pp. 204-210.
6. P. Basu and Griffin, J.H., "The Effect of Limiting Aerodynamic and Structural Coupling in Models of Mistuned Bladed Disk Vibration", *ASME Journal of Vibration, Acoustics, Stress and Reliability in Design*, Vol. 108, January 1986, pp. 50-55.

7. J.H. Griffin and Sinha, A., "The Interaction Between Mistuning and Friction in the Forced Response of Bladed Disk Assemblies", *ASME Journal of Engineering for Gas Turbines and Power*, Vol. 107, January 1985, pp. 205-211.

Several ideas have been developed in this area of research. A key approach to the problem of blade vibration that has been developed in [5] is the use of "mistuning statistics." In essence this idea is that in mistuned rotors individual blades behave in an almost unpredictable fashion. However, large groups of blades will always contain some blades that have small vibratory stresses, some that have large stresses, and many with stresses that lie in between. This statistical distribution of blade vibratory stresses is essentially the same for any large group of blades. It is the parameters which characterize this distribution which need to be determined by testing and analysis. It is this distribution which can be used to predict the response of the worst blade on the worst engine of the fleet and, consequently, predict engine durability. During this research program, computer codes have been developed to predict these types of statistics for a given bladed disk assembly. In [6] the codes were improved by including aerodynamic coupling. The code was used to study the effect of changing various system parameters on amplitude scatter. Gas density, the number of blades on the disk, disk stiffness, and the engine order of the excitation were considered. The results were used to draw some conclusions about how to improve laboratory tests and component design.

Lastly, in [7] the extent to which mistuning affects friction damper design was studied. It was found that when the disk was mistuned, the amplitude reduction ratio and the optimum value of friction slip force for the worst blade on the disk was not significantly different from those calculated from the simpler tuned system theory. This indicates that, from a practical point of view, the mistuning problem and the friction damper design problem are decoupled and that mistuning does not have to be directly considered in designing friction dampers to control resonance.

In summary the research performed under this grant has provided the basis for two new approaches for understanding and controlling bladed disk response. Methods now exist that provide the basis for designing friction dampers that may be use to control stage flutter. In addition, a new approach (mistuning statistics) has been developed which should bridge the gap between mistuning theory and its actual application in engineering design.

3. FRICTION-FLUTTER INTERACTION

This section contains copies of the following papers:

1. A. Sinha and Griffin, J.H., "Friction Damping of Flutter in Gas Turbine Engine Airfoils", *AIAA Journal of Aircraft*, Vol. 20, April 1983, pp. 372-376.
2. A. Sinha and Griffin, J.H., "Effects of Friction Dampers on Aerodynamically Unstable Rotor Stages", *AIAA Journal*, Vol. 23, No. 2, February 1985, pp. 262-270.
3. A. Sinha and Griffin, J.H., "Stability of Limit Cycles in a Multi-Degree-of-Freedom Model of an Aerodynamically Unstable Rotor Stage with Friction Dampers", *Journal of Sound and Vibration*, Vol. 103, December 1985, pp. 341-356.
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